BUILDING A CONTINUING EDUCATION PROGRAM FOR EMBEDDED SYSTEMS WITH LABS AND DISTANCE SUPPORT

Sam Siewert
University of Colorado, Department of Electrical and Computer Engineering
Boulder, CO USA
Sam.Siewert@Colorado.EDU

Mario Vidalon
University of Colorado, Center for Advanced Engineering and Technology Education
Boulder, CO USA

In spring 2000 the University of Colorado Electrical Engineering department and CAETE (Center for Advanced Engineering and Technology Education) launched an Embedded Systems Certificate program with two new courses taught by two adjunct professors from industry. Since this time the program has become self-funding, has added three additional courses, and has built out a shared lab for embedded systems using funding from the CU Engineering Excellence fund and grants from local industry. This paper reports on how the successful certificate program was built and innovative new approaches being investigated for distance lab support in a fifth class added this spring 2007, Real-Time Digital Media and Control Systems. The approach taken and lessons learned at CU are reported to assist other institutions designing similar programs.

Genesis of the Embedded Certificate Program

The Embedded Certificate Program at the University of Colorado Boulder was motivated by the experience gained working with undergraduate and graduate students from Electrical Engineering and Computer Science on research and development projects with the NASA Jet Propulsion Laboratory to build semi-autonomous Space Shuttle and deep space probe science payloads. Dr. Linden McClure and Dr. Sam Siewert, Ph.D. students at the time, lead hardware and software development programs to build a technology demonstration payload that was flown on STS-85 (Space Transportation System flight 85) in 1997. Based on this experience, McClure and Siewert returned to CU as post doctoral adjunct faculty from industry in 2000 to cofound the Embedded Certificate program with the goal to provide CU students with coursework providing full embedded engineering lifecycle experience. This goal was well aligned with feedback the Electrical and Computer Engineering Department received from local companies who also were requesting students get more embedded lifecycle design experience. The program was started in 2000 with two courses offered as senior year undergraduate / first-year graduate curriculums: ECEN 5613/4613 – Embedded System Design and ECEN 5623/4623 – Real-Time Embedded Systems. Since 2000, the program has been awarded several CU Engineering Excellence Fund grants and a private grant from Qualcomm to improve lab facilities and to increase enrollment and course offerings in the certificate program. Three new courses have been added including: ECEN 5633/4633 – Hybrid Embedded Systems, ECEN 5543 – Software Engineering of Standalone Systems, and ECEN 5033/4033 – Real-Time Digital Media and Control Systems. On average three of the courses are offered each semester with enrollments of twenty-four or more students in each class. Since the inception of the program hundreds of students of completed the three course requirement for the certificate and the certificate has become well respected in local industry and sought after by continuing education students in the Boulder/Denver area.

Distance Learning Challenges

Given the success of the Embedded Certificate Program, student backlog has developed and has required occasional summer offerings of courses to ensure that local demand is met. However, additional demand from students outside the Denver metropolitan area has not been met to date due to the challenges associated with offering the hardware-based labs as distance courses. The software engineering courses have been offered as distance learning options through CAETE (Center for Advanced Engineering and Technology Education) at CU Boulder. The labs designed for ECEN 5613/4613 – Embedded System Design, ECEN 5623/4623 – Real-Time Embedded Systems, and ECEN 5633/4633 – Hybrid Embedded Systems all require use of costly equipment ($1,000.00 or more) that remote students can't easily purchase, borrow, or access remotely. For example, in ECEN 5623/4623 students use the Wind River Systems VxWorks RTOS on embedded microprocessor systems that interface to computer vision and robotics subsystems. Not wanting to over simplify these successful course simply to make them more manageable for distance learning, the courses have continued to require some amount of on-campus presence to complete labs and projects. Many industry students may be occasional distance learners making use of the CAETE Tegrity on-demand lectures.

Experiment to Evaluate Distance Learning with Labs

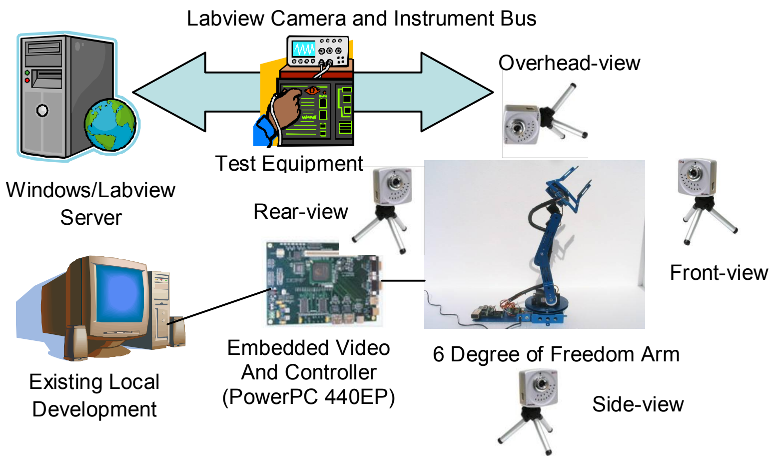
Lab courses with costly hardware such as optics, robotics, embedded systems, and many others in electrical engineering have a reputation for being challenging if not impossible to offer as effective remote curriculums without omission of the hands-on hardware design and characterization components that make these courses so valuable to students and to the institutions that hire them after graduation. Dr. Alan Mickelson has taken on this challenge with an NSF funded research project to offer ECEN 4699 – Optical Circuits in cooperation with several other universities including University of Houston offering similar courses in optics. This research is employing the University of California BEAR (Berkeley Evaluation and Assessment Research) Assessment System to evaluation the effectiveness of optical circuits labs completed by students both on-campus and accessing the same labs remotely via a web interface to optics benches instrumented, monitored, and controlled using Labview software and firewire cameras. Based upon initial success of the first phase of this research, a second phase has been initiated and expanded to include ECEN 5033 – Real-Time Digital Media and Control Systems to evaluate the ability to provide remote lab interfaces to robotics, computer vision, and digital video curriculum. ECEN 5033 was created based upon student feedback given in course evaluations for ECEN 5623 – Real-Time Embedded Systems where about half of students responding indicated that they would like to see a Linux-based course offered.

Use of Linux-Based Digital Media and Robotics Labs to Evaluate Remote Access

The Linux operating system has three distinct advantages over a proprietary RTOS: a wide variety of open source applications and drivers can be incorporated into the curriculum, Linux has distinctly better remote access features and Linux can be easily installed on commonly available x86 home PCs by remote students. Given these characteristics of ECEN 5033, it is believed that this course may be able to provide remote distance learners similar hands-on experience to ECEN 5623 using a combination of remote lab support methods including: home lab set-up with Linux and purchase of relatively low-cost digital video PCI cards, remote access to more costly robotics setups, and CAETE distance learning support with Tegrity on-demand lectures. The remote robotics lab stations will be equipped similarly to the remote optics labs with Labview, firewire cameras showing the arm from top, side, and frontal views, Labview test equipment telemetry, and remote login to Linux-based embedded control systems for computer vision and closed loop digital control for arm tasking. Figure 1 shows the basic remote robotics/computer-vision lab station that is proposed for remote access to distance students of

ECEN 5033/4033. This remote access robotics/computer-vision lab bench is called MARVEL (Multi-Media, Advanced Robotics, and Vision Embedded Lab).

Figure 1. MARVEL Bench



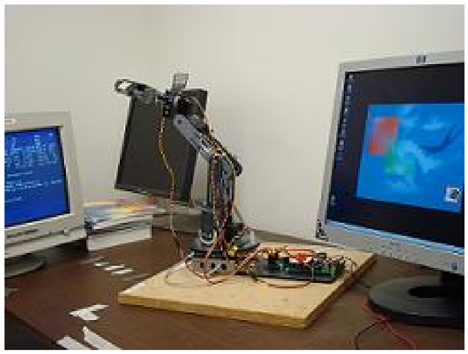
Phase One of the Remote Robotics/Digital Video Lab Assessment

The effectiveness of the ECEN 5033 remote access robotics lab and experience for distance students will be evaluated in a two phase approach. In phase one, the offering this spring 2007 will include on-campus students participating in the robotics extended lab projects and distance students participating in digital video projects without the robotic arm. During this first offering, all students will complete basic labs using the remote access Linux systems and robotic simulations and digital video transport stream analysis tools. These labs will include BEAR assessment construct maps (theory presented), items design (lab exercises), outcome space (lab responses), and measurement models (grading). All students will participate in these basic labs including on-campus and remote so that performance maps for both groups can be compiled and compared. During this spring 2007, students are being offered the choice of an extended lab project focused on digital video or robotics/computer-vision explorations in greater depth than the basic labs, similar to projects in ECEN 5623, but based on instructor requirements specification rather than student proposals. For spring 2007 only on-campus students will be allowed to complete the robotics extended lab projects and BEAR assessments will be used to form a performance map baseline. For the digital video both remote and on-campus students are expected to complete the extended lab projects providing a direct comparison assessment of remote and on-campus performance.

The MARVEL Remote Access Lab Bench

To evaluate MARVEL, a robust 6-DOF (Degree of Freedom) arm was first tested in ECEN 5623/4623 which can use all off-the-shelf controllers and which has good repeatability and reliability for teleoperations. The arm selected is built by Crust Crawler and is a significant improvement over much lower cost arms built by ECEN 5623/4623 students in the past. Rather than trying to further lower cost and have remote distance learners run a full robotics home lab, the idea of MARVEL is to provide a robust 24/7 access remote robotics/computer-vision experimentation and project development platform for both traditional in-residence 5623 students and for remote 5033 distance learners. Common microprocessor hardware is used to dual-boot either VxWorks or Linux. The evalution set-up for MARVEL is shown in Figure 2. The phase 1 evaluation arm was first used by an on-campus student project group including: Jonathan Bruneau, Richard Devore, and Abhishek Ramesh Keshav. This group designed a custom controller for the arm which will be replaced with an off-the-shelf Pololu eight channel servo controller. A full motion MPEG video of the MARVEL phase 1 evaluation arm can be found on the ECEN 5033 video server - Crust Crawler 6-DOF Arm Video Footage. One interesting aspect of MARVEL and the remote student distance learning goal for ECEN 5033 is that it will inherently help reinforce advanced constructs in robotics forcing students to examine tele-operation, semi-autonomous shared control, and fully autonomous tasking using remote monitoring of their labs and project experiments.

Figure 2. MARVEL Phase 1



Phase Two of the Remote Robotics/Digital Video Lab Assessment

ECEN 5033 is planned for permanent inclusion into the Embedded Certificate Program at CU based on good enrollment and the fact that it meets student and industry demand for soft real-time curriculum that is Linux-based. The viability of distance offering via CAETE will be further evaluated during phase two when the full MARVEL remote access lab is implemented. The BEAR assessment performance map for each student, remote and on-campus, will be compiled into class maps each semester to determine the long term effectiveness of MARVEL for distance learners compared to on-campus students. The key to quality pedagogical analysis in this research is the assessment design for using construct maps, items design, outcome space, and measurement models that are hidden from student participants. The course is based upon a well tested formula of one third real-time theory (soft real-time for 5033, hard real-time for 5623), one third lab practice, and one third exploratory learning during the extended lab project work. This curriculum design fits the BEAR assessment well with real-time theory mapped to a construct map as shown in Table 1.

Final Analysis for Distance Learning Effectiveness Assessment

The items design consists of four basic labs done by all students and a six-week multi-part extended set of labs planned for 5033. Each lab will consist of questions at the novice, knowledgeable, practitioner, and designer construct levels so that performance maps can be developed for each student as they progress through the labs. In the last labs, successful students would be expected to transition from mostly novice performance to practitioner or designer levels of performance. The BEAR assessment provides a rigorous and objective outcome space and measurement model whereby students are not only graded in the traditional sense, but performance mapped by correct/incorrect answers to lab questions designed at the construct performance levels in Table 1. Each student’s performance map is then a plot of student responses for the construct level being evaluated as the course progresses. The beginning of course class map for all students both distance and on-campus for all construct levels will be assessed with an initial quiz and the first two basic labs for novice and knowledgeable construct levels. The second two basic labs will cover knowledgeable and practitioner construct levels and the final multi-part extended project labs will provide assessment for practitioner and designer construct levels of performance. The student class maps will be divided into on-campus and remote so that the effectiveness of the curriculum and MARVEL remote lab can be evaluated for both groups.

Table 1.

Performance Level	**Computer Vision**	**Real-Time Software Development**	**Robotics**	**Digital Video**
Designer	Stereo ranging, optical models, calibration, non-linear corrections	Deadline analysis with Rate Montonic, EDF/LLF, or QoS models, tuning, and optimizations	Comparison of autonomous, shared control, and teleoperation architectures	Hardware acceleration for encoder/decoder, trick play operations, multiplexing streams, grooming
Practitioner	Background elimination, segmentation, centroid calculation, linear models	Rate monotonic or dynamic scheduling policy, state machine design, synchronization, deadlock avoidance, and priority inversion	Kinematics and equations of motion models, calibration, closed loop digital control design, and component characterization	MPEG codec and transport standards and formulation
Knowledgeable	Kernel-based edge enhancement, color space, resolution	Threading, best-effort scheduling, main thread + ISRs	End effector reachability analysis, dead reckoning, arm tasking	Color space (pixels), frame space (windows), and frame sequences (time)
Novice	Acquisition, focus, lighting, observed field of view	Re-entrant functions and basic threads for services	Degress of freedom, joint rotations to pick and place objects	Frame rate, resolution, color palettes

References

Kennedy, Cathleen, (2005). The BEAR Assessment System: A Brief Summary for the Classroom Context, BEAR Center Technical Report Series No. 2005-03-01.

Tzafestas, Costas & Palaiologou, Nektaria, (2006). Virtual and Remote Robotic Laboratory: Comparative Experimental Evaluation, IEEE Transactions on Education, Vol. 49, No. 3.

Hirzinger, Gerd, Brunner, Bernhard, Dietrich, Johannes & Heindl, Johann (1993). Sensor-Based Space Robotics – ROTEX and Its Telerobotic Features, IEEE Transactions on Robotics and Automation, Vol. 9, No. 5.

Fabri, D., Falsetti, C., Ramazzotti, S. & Leo, T. (2004). Robot Control Designer Education on the Web, IEEE Proceedings of 2004 Conference on Robotics and Automation, New Orleans.

Benhaddou, D., Gurkan, D., Kodali, H., McKenna, E., Mickelson, A. & Barnes, F. (2006). Online Laboratory for Optical Circuits Courses: Effective Concept Mapping, Proceedings of the 2006 ASEE Gulf-Southwest Annual Conference.